TECHNICAL REPORT

Contract Title:	Infrared Algorithm Development for Ocean Observations with EOS/MODIS
Contract:	NAS5-31361
Type of Report:	Semi-Annual
Time Period:	January- June 2002
Principal Investigator:	Otis B. Brown RSMAS/MPO University of Miami 4600 Rickenbacker Causeway Miami, Florida 33149-1098

INFRARED ALGORITHM DEVELOPMENT FOR OCEAN OBSERVATIONS WITH EOS/MODIS

Abstract

Efforts continue under this contract to develop and validate algorithms for the computation of sea surface temperature (SST) from MODIS infrared measurements. These include radiative transfer modeling, comparison of *in situ* and satellite observations, development and evaluation of processing and networking methodologies for algorithm computation and data access, evaluation of surface validation approaches for IR radiances, and participation in MODIS (project) related activities. Activities in this contract period have focused on field campaigns, analysis of field data, analysis of MODIS SST retrievals, and preparation of publications and presentations.

A. NEAR TERM OBJECTIVES

MODIS Infrared Algorithm Development and Maintenance

A.1. Algorithmic development efforts based on experimental match-up databases, radiative transfer models and inter-satellite comparisons

A.2. Interaction with the MODIS Instrument Team through meetings and electronic communications, and provide support for MCST activities.

A.3 Maintain and develop at-sea instrumentation for MODIS SST validation.

A.4 *In situ* validation cruises for the MODIS IR bands.

A.5 Development and population of the MODIS Matchup Data Base.

A.6 Interactions with international groups.

MODIS SST – Scientific Research

A.7 Study thermal structure of ocean-atmosphere interface.

A.8 Development of optimal skin-SST validation strategy.

A.9 MODIS cloud cover studies.

Overarching Contract Activities

A.10 Provide investigator and staff support for the preceding items.

B. OVERVIEW OF CURRENT PROGRESS

January – June 2002

Activities during the past six months have continued on the previously initiated tasks. There have been specific efforts in the areas of: (a) cruises to acquire MODIS infrared validation data and (b) refinement of an interim SST retrieval algorithm based on match-up with AVHRR Pathfinder data. In addition, previously initiated activities, such as team related activities, continue, as have episodic efforts associated with MODIS characterization and response.

Special foci during this six-month period have been:

1) Refinement of the SST retrieval algorithm based on match-ups with surface data for the derivation of the atmospheric correction algorithm for SST retrieval.
2) Prepare the at-launch algorithms for the *Aqua* MODIS.
3) Continuation of the analysis of measurements from M-AERI research cruises.
4) Continuation of routine data collection on the *Explorer of the Seas.*
5) Preparation and participation in the cruise of the *USCGC Polar Star* from Valparaiso, Chile, to Seattle (March - April 2002).
6) Maintenance of the at-sea hardware.
7) Continue development of a purpose-built computer database for validation cruise data and associated satellite measurements.
8) Implementation of various SST data assimilation approaches.
9) In collaboration with Dr B. Ward of the CIMAS, and Dr. M. Donelan of the University of Miami a study of the thermal skin layer with his micro-profiler and the M-AERI, in the University of Miami – Rosenstiel School ASIST facility, has begun (with ONR funding).
10) Prepare for publication the results from the *2nd International Infrared Intercomparison* at the University of Miami – Rosenstiel School (with funding from NOAA-NESDIS, ESA and EUMETSAT).

B.1. Algorithmic development efforts based on experimental match-up databases, radiative transfer models and inter-satellite comparisons.

The generation of the matchup-data base of MODIS brightness temperatures and *in situ* measurements from drifting buoys and the M-AERI (see B.5 below), and this has led to the refinement of atmospheric corrections algorithm and an improved estimate of the residual errors. The distribution of the buoys currently in the database is shown in Figure 1a, for only those that have passed the highest quality control tests. These include screening of the in situ temperature themselves, and the strictest cloud screening of the MODIS brightness temperatures; additionally the satellite zenith angle measured at the buoy has to be $\leq 45^o$. There are 2409 points that meet these criteria. The distribution, as a function of *in situ* temperature, of the residual errors in the MODIS temperatures retrieved from the brightness temperatures measured in Bands 31 and 32, using the semi-empirical coefficients derived from comparisons with near-coincident AVHRR Pathfinder SSTs (Figure 1b) and using the radiative transfer simulations (Figure 1c). The residual errors are shown in Figures 1b and 1c. The statistics of the errors of the semi-empirical algorithm are somewhat better than those of the radiative transfer coefficients. However, the shape of the distribution at higher temperatures is more realistic for the radiative transfer coefficients; the increase in positive bias in the tropics is a consequence of the development of the diurnal thermocline.

A highlight of the current reporting period was the arrival of the first light data from the *Aqua* MODIS. The first data arrived at RSMAS in time to be processed to mapped images of skin SST and sent to Toronto for display during the special MODIS session of the IGARSS Symposium. All within 72 hours of the data being taken. An example of the 11µm skin SST over the Indian Ocean is shown in Figure 2. Initial analysis of the imagery indicates that the *Aqua* MODIS does not have many of the problems found in the *Terra* MODIS, such as the detector banding, mirror sidedness, and across-scan effects caused by residual uncertainties in the correction for the angular dependence of the reflectivity of the mirror coating.

B.2. Interaction with the MODIS Instrument Team through meetings and electronic communications, and provide support for MCST activities.

Throughout this reporting period there has been continuing interaction with Bob Evans (Contract NAS5-31362) and others at RSMAS on a daily basis to discuss the remediation of MODIS instrumental issues; improvements to atmospheric correction algorithms, and numerous telephone discussions with Wayne Esaias, MODIS Oceans Team Leader, on MODIS SST retrievals.

Peter Minnett was invited to attend the VIIRS Operational Algorithm Team Meeting held at the NOAA Science Center, Camp Springs, MD, on 7 June 2002, and gave a presentation entitled "Sea-surface temperature - experience gained from MODIS." He was also invited to give a presentation at the NPOESS Workshop' held on June 23, 2002, in Toronto, Canada, in conjunction with the IEEE International Geosciences and Remote Sensing Symposium. In the special MODIS Session at this symposium, Minnett gave the presentation "Sea-surface temperature measured by the Moderate Resolution Imaging Spectroradiometer (MODIS)", with R.H. Evans, E.J. Kearns and O.B. Brown as co-authors.

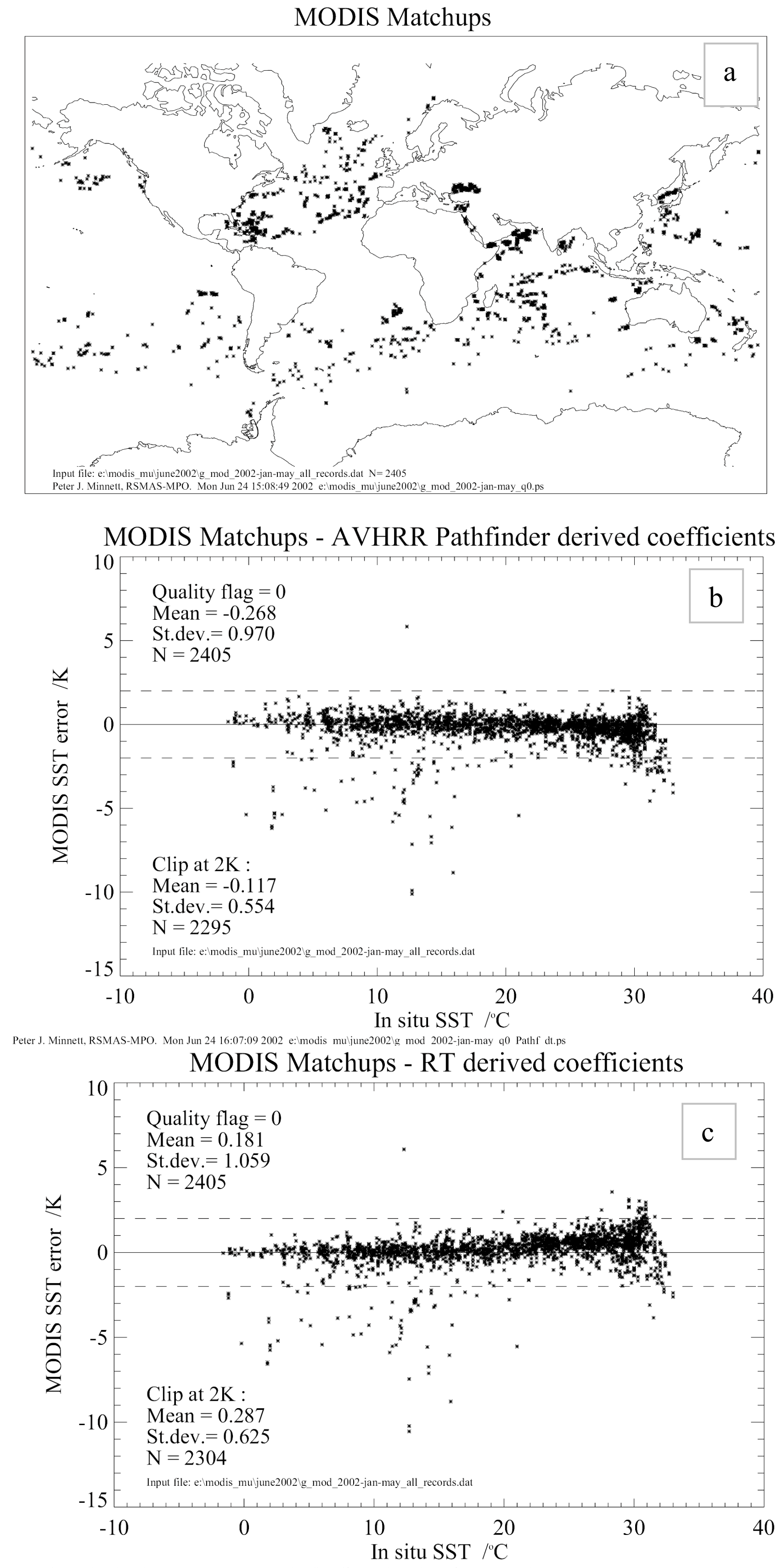

Figure 1.

(a) The distribution of match-ups between *Terra* MODIS brightness temperatures and in situ measurements

(b) The residual errors in SST retrieved using an atmospheric correction algorithm with coefficients derived by comparisons with AVHRR Pathfinder SSTs.

(c) The residual errors in SST retrieved using an atmospheric correction algorithm with coefficients derived by radiative transfer simulations.

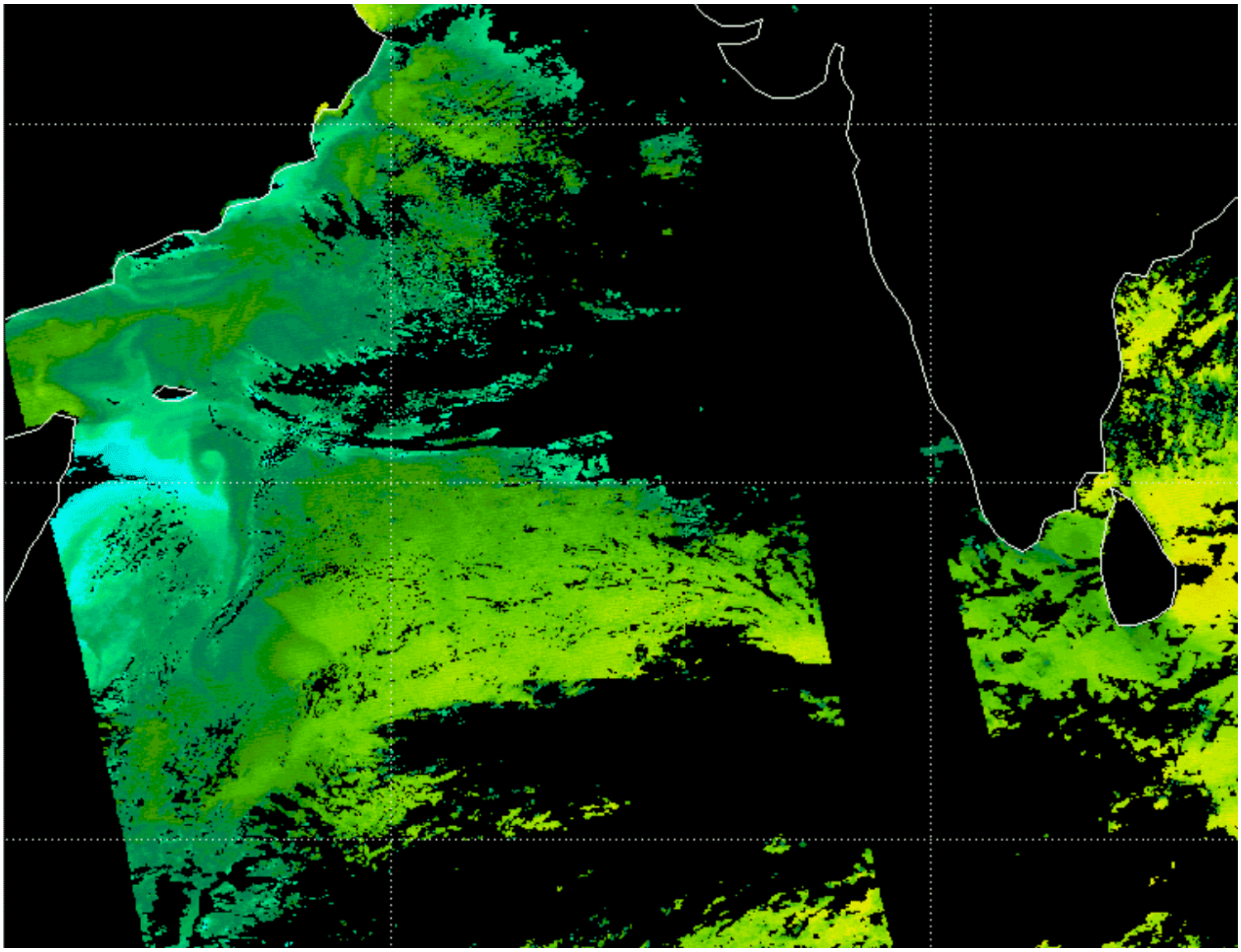

Figure 2. First light data from the Aqua MODIS. 4km global 11µm daytime SST over the Arabian Sea and the western Indian Ocean. 24 June 2002.

B.3 Maintain and develop at-sea instrumentation for MODIS SST validation.

The routine maintenance of the M-AERIs and other ancillary sensors used in MODIS SSTs continues without significant issues. All three M-AERIs are now rebuilt into stainless-steel, weather-proof enclosures.

B.4 *In situ* validation cruises for the MODIS IR bands.

MAERI-1 is permanently installed on the *Explorer of the Seas*, which undertakes weekly cruises in the Caribbean Sea (Figure 3). The eastern track has been followed since the ship entered service in late October 2000, and the western track has been followed on alternate weeks since mid April, 2002. The ship returns to Miami each Saturday at which time the data are retrieved and taken to RSMAS. The data return has been very good (Figure 4).

Figure 3. The new western track (top) and the eastern track (bottom) of the *Explorer of the Seas* through the Caribbean area. The tracks are followed on alternate weeks.

MAERI-2 was embarked on the *USCGC Polar Star* in Valparaiso, Chile, for the return voyage through the Pacific Ocean. Because of heavy port traffic, the ship was not able to dock at the quayside, and had to remain at anchor offshore. As a consequence, the M-AERI could not be mounted in its operating position on the top of the bridge as this requires a dockside crane. The ship was able to tie up at the dockside at Callao, the port of Lima, Peru, the subsequent port of call, and the M-AERI was successfully installed and the measurements were begun when the ship sailed 19 March, 2002. The track is shown in Figure 5. Again, the instrument functioned well and a wide range of environmental conditions were experienced during the cruise.

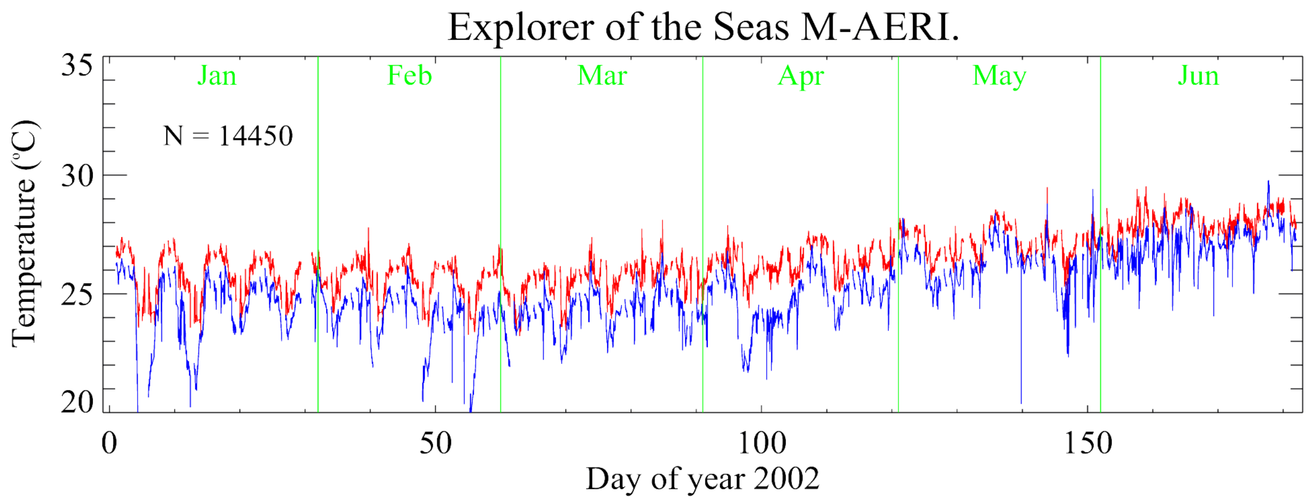

Figure 4. Skin SST and near-surface air temperatures measured by MAERI-1 on the *Explorer of the Seas*, from January to June, 2002.

B.5 Development and population of the MODIS Matchup Data Base

The development of a data base of matchups between MODIS brightness temperatures, and derived SSTs, and in situ validation measurements from buoys and M-AERIs continues. This has already been used to determine the errors in the MODIS SST retrievals in the 11µm atmospheric window (see B.1 above) although the samples do not yet sample adequately the full range of atmospheric variability. The data base is modeled on the successful Miami Pathfinder AVHRR Matchup Database that has been widely used in the community.

B.6 Interactions with international groups.

It is planned to make the M-AERI measurements available to the Advanced Along-Track Scanning Radiometer (AATSR) Team at the University of Leicester for validating the AATSR SST retrievals. The AATSR is the third in the series of dual-view imaging radiometers to fly on European polar orbiting satellites, and is part of the scientific payload of the *ENVISAT* satellite. In return for the M-AERI data, we will receive copies of AATSR data which will be used in comparative studies with MODIS SSTs. By measuring the same swath of the earth's surface at two view angles, the AATSR provides a direct measurement of the effect of the atmosphere on the infrared signals, thereby permitting an alternative approach to the conventional multi-channel atmospheric correction algorithms used by MODIS. The AATSR has three channels that match quite well bands 20, 31 and 32 of MODIS. With funding provided by the UK AATSR Team, Peter Minnett attended the AATSR Commissioning Phase Readiness Review at the Space Research Centre, University of Leicester, UK, in January, 2002.

Dr. Peter Minnett has been invited to join the Science Team Meeting of the GODAE (Global Ocean Data Assimilation Experiment) High Resolution Sea-Surface Temperature (GHRSST) Pilot Project. The GHRSST-PP objective, to provide global SSTs at a spatial resolution of 10km or better, on a 6-hr time step, requires the merging of SST fields from a wide range of satellite sensors operating both in the infrared and the microwave spectral regions, and the merging of these disparate data sets in a

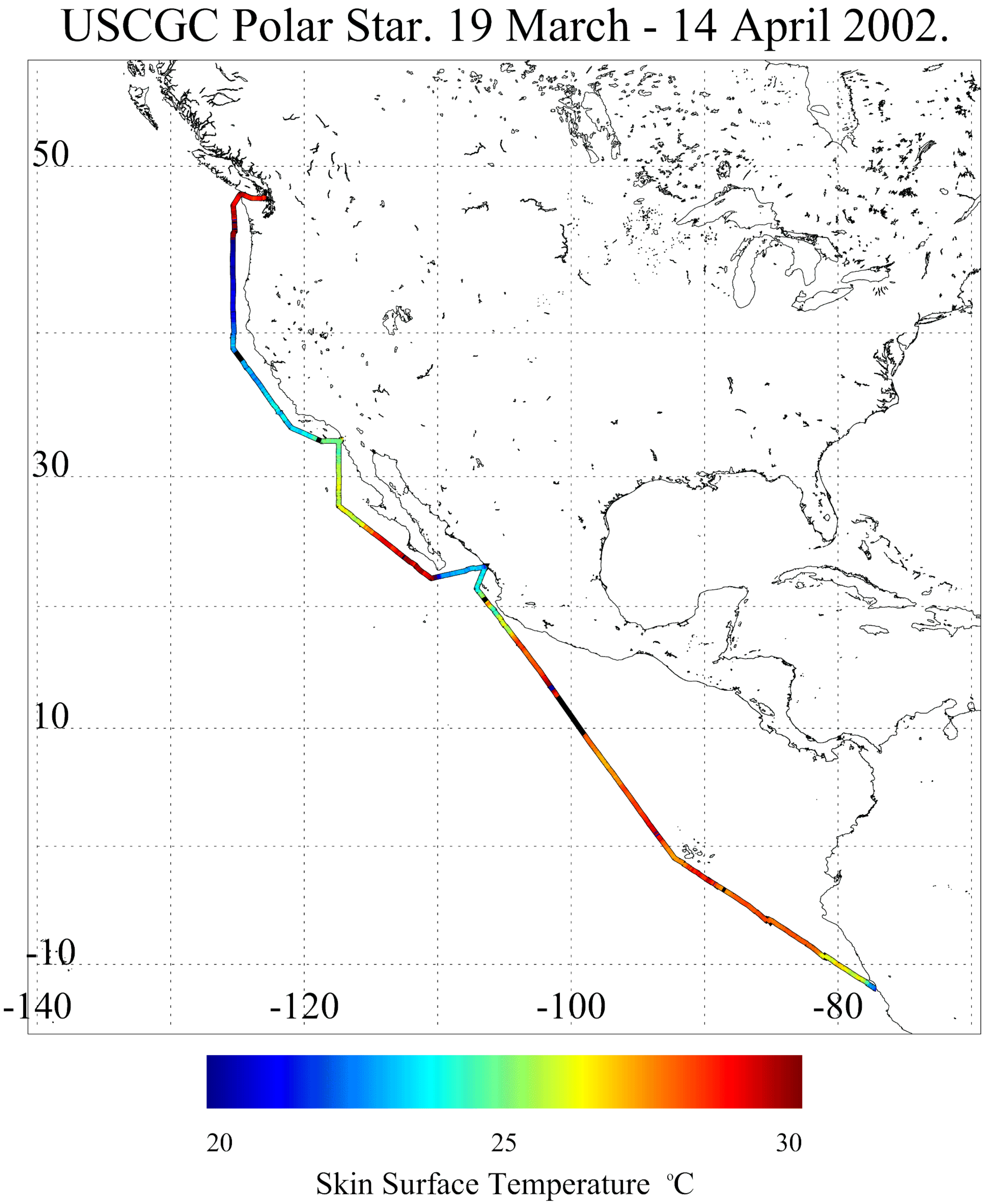

Figure 5. Track of the *Polar Star* from Callao to Seattle. The track is colored by the M-AERI measurements of skin SST; black indicates missing data, resulting from the instrument being covered during periods of heavy rain.

physically meaningful manner is a subject ripe for intense research. Although the mechanism for full US participation in GHRSST is not yet clear, the potential contribution of MODIS SSTs to this is very significant, and desired by the GHRSST international Science Team.

MODIS SST – Scientific Research

B.7 Study thermal structure of ocean-atmosphere interface.

Jennifer Hanafin was awarded the Ph.D. degree by the University of Miami in May, 2002. Her thesis research included analyses of M-AERI data taken on several cruises for AVHRR and MODIS SST validation. One aspect of this analysis was the wind speed dependence of the seas surface emissivity which can be derived from the M-AERI spectral measurements of oceanic and atmospheric infrared emission. Prior results, based on modeling studies (Masuda, K., T. Takashima and Y. Takayama, Emissivity of pure and sea waters for the model sea surface in the infrared window region. *Remote Sensing of Environment* **24**: 313-329, 1988; Watts, P., M. Allen and T. Nightingale, Sea surface emission and reflection for radiometric measurements made with the along-track scanning radiometer. *Journal of Atmospheric and Oceanic Technology,* **13**: 126-141, 1996) showed a marked dependence of the emissivity on wind speed, but such a dependence is largely absent in the at-sea measurements (Figure 6). This indicates that the contribution to the error budget of validation of the satellite-derived SST has a smaller contribution to uncertainties in the surface wind speed, or surface roughness, is smaller than previously thought. Another result is that the skin layer is thinner than previously thought, and appears less variable in terms of net heat flux than previously believed. Another result is that it may indeed be possible to measure the ocean-atmosphere heat flux by using the wavelength dependence of the emission depth of thermal infrared radiation measurement by the M-AERI. This has been demonstrated in the laboratory by McKeown *et al.* (McKeown, W., F. Bretherton, H.L. Huang, W.L. Smith, and H.L. Revercomb, Sounding the skin of water: sensing air-water interface temperature gradients with interferometry., *J. Atmos. and Oceanic Tech.*, **12**, 1313-1327., 1995).

With funding from ONR a study has begun of the thermal skin layer and subsurface temperature structure in the RSMAS ASIST (Air-Sea Interaction Salt Water Tank). ASIST was designed for studies relevant to air-sea interaction including remote sensing, turbulence, gas transfer, wave dynamics, surface chemistry, spray and aerosol generation, and interfacial thermodynamics. The 15 meter long ASIST is equipped with a wind tunnel (0-30 m/s), programmable wavemaker, water temperature control, water current control, turbulence and wave instrumentation. This is in collaboration with Dr B. Ward of the CIMAS, and Dr. M. Donelan of RSMAS.

B.8 Development of optimal skin-SST validation strategy.

During the last week of May, 2001 an international workshop for the comparison and calibration of ship-board infrared radiometers that are being used to validate the skin sea-surface temperatures derived from the measurements of imaging radiometers on earth observation satellites, was held at RSMAS. Included are laboratory measurements with the newly-developed NIST Transfer Radiometer

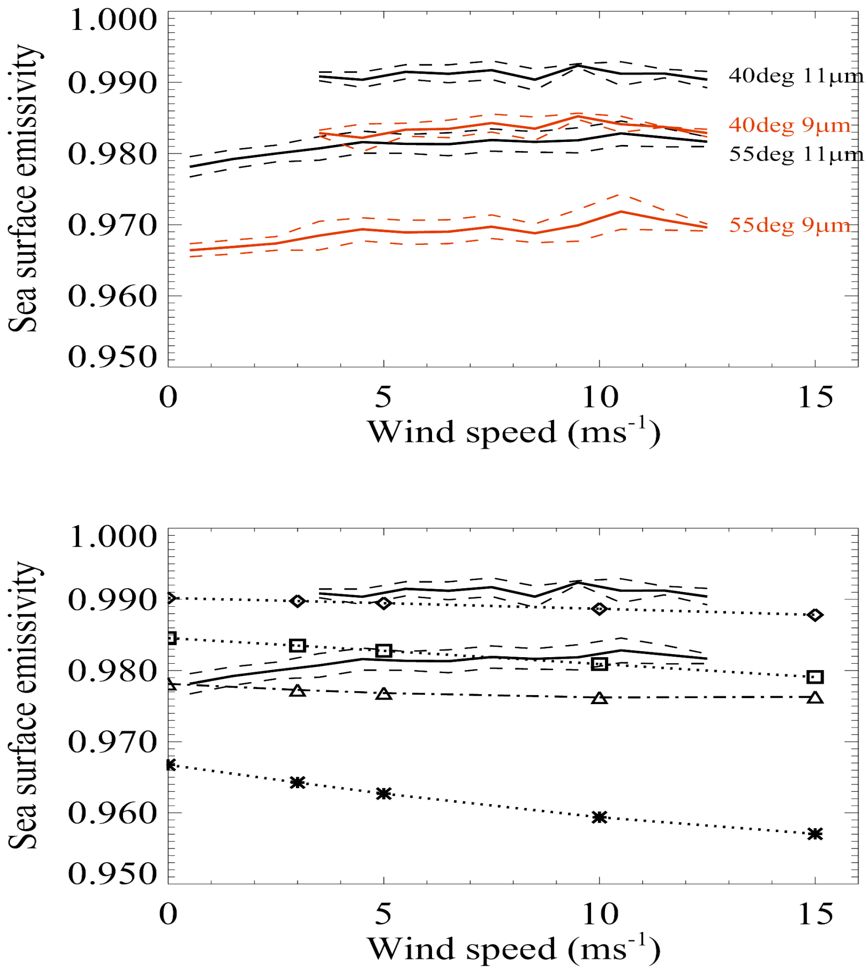

Figure 6. Observed mean (solid lines) and standard deviation (dashed lines) of sea surface emissivity in 1ms^{-1} wind speed bins for 9µm and 11µm at 40° and 55° incidence angles (top). Below, the solid lines are the measured 11µm emissivity for the 40° and 55° views, the dashed line with triangular markers represents values predicted by *[Watts et al., 1996]* for 55° at 11µm (the coefficients given in that paper are valid for 52°-55° viewing angle). The dotted lines are those predicted by *[Masuda et al., 1988]* for 40° (diamonds), 50° (squares) and 60° (asterisks). From: J.A. Hanafin, Ph.D. Thesis, University of Miami, 2002.

(TXR), and against NIST-certified black-body calibration targets, and an intercomparison of the radiometers on a short cruise on board the R/V F.G. *Walton-Smith* in local waters around Miami. Table 1 shows the instruments that took part in the workshop. The measurements are being analyzed, and results will be prepared for publication. Table 1 shows the characterization of three black body calibration targets, derived by measurements taken in conjunction with the EOS-TXR (from Rice *et al.*, in preparation). The results of the at-sea measurements are presented in Table 2, which shows the statistics of the differences in brightness temperatures measured by pairs of radiometers on the ship (from Barton *et al.*, in preparation). These are very good and indicate that the measurements of these radiometers can be used individually or in concert, to validate the skin SSTs retrievals from the measurements of satellite radiometers. This activity is funded by NOAA, ESA and EUMETSAT.

Table 1. Infrared radiometers that participated in the campaign.

Instrument	Institution	Lab.	Sea	P.I.
TXR (Transfer radiometer)	NIST, USA	Yes	No	J. Rice
M-AERI (Marine-Atmospheric Emitted Radiance Interferometer)	RSMAS, U. Miami.	No	Yes	P. Minnett
SISTeR (Scanning Infrared Sea Surface Temperature Radiometer)	RAL, UK.	Yes	Yes	T. Nightingale
DAR011	CSIRO, Australia.	Yes	Yes	I. Barton
CIRIMS (Calibrated InfraRed In situ Measurement System)	APL, U. Washington.	No	Yes	A. Jessup
ISAR-5 (Infrared SST Autonomous Radiometer -5)	JRC, EEC.	Yes	Yes	C. Donlon
Near-Nulling Radiometers	NASA JPL	Yes	Yes	S. Hook
Tasco (off-the-shelf)	CSIRO, Australia	Yes	Yes	I. Barton

Table 2. Characterization of the blackbody calibrators (Rice *et al*., in preparation).

Quantity	RSMAS BB	JPL BB	CASOTS U. Leicester BB
Spacing (mm)	64	128	114
$1\text{-}\varepsilon_{BBX}$	1×10^{-5}	8.379×10^{-3}	9.457×10^{-3}
$1\text{-}\varepsilon_{BBX}$ fitting uncertainty	7×10^{-4}	8.43×10^{-4}	6.44×10^{-4}
ε_{BBX}	1.0000	0.9916	0.9905
ε_{BBX} fitting uncertainty	0.0007	0.0008	0.0006
Intercept (W cm^{-2} sr^{-1})	-1.9×10^{-7}	-8.96×10^{-6}	-1.047×10^{-5}
Intercept fitting uncertainty (W cm^{-2} sr^{-1})	8×10^{-7}	9.4×10^{-7}	7.2×10^{-7}
T_s (°C)	N/A	31.57	33.82
T_s fitting uncertainty (°C)	N/A	0.28	0.05

Table 3. Means and standard deviations of the differences in skin SST differences measured by pairs of radiometers for the entire cruise period. (Barton *et al*., in preparation).

Radiometer Pair	Mean (K)	Std.Dev. (K)	N
M-AERI - ISAR	0.002	0.135	80
M-AERI - SISTeR	0.046	0.066	144
M-AERI - JPL NNR	0.007	0.114	148
M-AERI - DAR011	-0.008	0.076	149
ISAR - SISTeR	0.038	0.101	79
ISAR - JPL NNR	0.026	0.142	81
ISAR - DAR011	0.007	0.114	80
SISTeR - JPL NNR	-0.048	0.099	144
SISTeR - DAR011	-0.053	0.074	144
JPL NNR - DAR011	-0.014	0.103	148

B.9 MODIS cloud cover studies.

Some of the equipment installed on the *Explorer of the Seas*, such as the Total-Sky Imager and Ceilometer, are used to determine the amount and type of cloud cover present at the time of the satellite overpasses. These measurements have multiple applications including the determination of cloud-free conditions when MODIS SSTs are being compared to M-AERI measurements, and as data for validating cloud conditions determined from MODIS. This latter research has been conducted in collaboration with the group at The University of Alabama at Huntsville, and preliminary results were presented at the 82nd Annual Meeting of the American Meteorological Society, Orlando, FL. 13-17 January 2002.

C. INVESTIGATOR SUPPORT

January	O. Brown	R. Kolaczynski	
	M. Framinan	A. Li	
February	O. Brown	R. Kolaczynski	
	M. Framinan	A. Li	
March	O. Brown	R. Kolaczynski	P. Minnett
	M. Framinan		
April	O. Brown	R. Kolaczynski	P. Minnett
	M. Framinan	A. Li	
May	O. Brown	R. Kolaczynski	P. Minnett
	M. Framinan	A. Li	
June	W. Baringer	R. Kolaczynski	K. Maillet
	O. Brown	A. Kumar	J. Splain
	M. Framinan	A. Li	M. Szczodrak
	K. Kilpatrick		

D. FUTURE ACTIVITIES

D.1 Algorithms

a. Continue to develop and test algorithms on global retrievals
b. Evaluation of global data assimilation statistics for SST fields
c. Participate in research cruises
d. Continue radiative transfer modeling
e. Continue analysis of research cruise data
f. Continue to study near-surface temperature gradients
g. Continue planning of post-launch validation campaigns
h. Validation Plan updates (as needed)
i. EOS Science Plan updates (as needed)
j. Continued participation in MODIS Team activities.

D.2 Investigator support

Continue appropriate efforts.

D.3 Presentations and publications.

Prepare scientific results for publication in the refereed literature.

E. PROBLEMS

None of note.

F. PUBLICATIONS AND PRESENTATIONS

F.1 Refereed publications:

Donlon, C. J., P. J. Minnett, C. Gentemann, T. J Nightingale, I. J. Barton, B. Ward and J. Murray, 2001. Towards improved validation of satellite sea surface skin temperature measurements for climate research. *J. Climate*, 15, 353-369

A poor validation strategy will compromise the quality of satellite-derived sea-surface temperature (SST) products because confidence limits cannot be quantified. This paper addresses the question of how to provide the best operational strategy to validate satellite-derived skin sea-surface temperature (SST_{skin}) measurements. High quality in situ observations obtained using different state-of-the-art infrared radiometer systems are used to characterize the relationship between the SST_{skin}, the subsurface SST at depth (SST_{depth}) and the surface wind speed. Data are presented for different oceans and seasons. These data indicate that above a wind speed of approximately 6 ms^{-1} the *relationship between the SST_{skin} and SST_{depth}, is well characterized for both day and night time conditions by a cool bias of 0.17 ±0.07 rms. K. At lower wind speeds, stratification of the upper ocean layers during the day may complicate the relationship while at night a cooler skin is normally observed. Based on these observations, a long-term global satellite SST_{skin} validation strategy is proposed. Emphasis is placed on the use of autonomous, ship of opportunity radiometer systems for areas in areas characterized by prevailing low wind speed conditions. For areas characterized by higher wind speed regimes, well calibrated, quality controlled, ship and buoy SST_{depth} observations, corrected for a cool skin bias should also be used. It is foreseen that SST_{depth} data will provide the majority of in situ validation data required for operational satellite SST validation. We test the strategy using SST_{skin} observations from the Along Track Scanning Radiometer, that are shown to be accurate to ~0.2 K in the tropical Pacific Ocean, and using measurements from the Advanced Very High Resolution Radiometer. We note that this strategy provides for robust retrospective calibration and validation of satellite SST data and a means to compare and compile in a meaningful and consistent fashion similar data sets. A better understanding of the spatial and temporal variability of thermal stratification of the upper ocean layers during low wind speed conditions is fundamental to improvements in SST validation and development of multi-sensor satellite SST products.*

Hagan, D. and P.J. Minnett, AIRS Radiance Validation Over Ocean from Sea Surface Temperature Measurements. IEEE Transactions on Geoscience and Remote Sensing. Submitted.

This paper demonstrates the accuracy of methods and in situ data for early validation of calibrated Earth scene radiances measured by the Atmospheric InfraRed Sounder (AIRS) on the Aqua spacecraft. We describe an approach for validation that relies on comparisons of AIRS radiances with drifting buoy measurements, ship radiometric observations and mapped sea surface temperature products during the first six months after launch. The focus of the validation is on AIRS channel radiances in narrow spectral window regions located between 800-1250 cm^{-1} and between 2500 and 2700 cm^{-1}. Simulated AIRS brightness temperatures are compared to in situ and satellite-based observations of Sea Surface Temperature (SST) co-located in time and space, to demonstrate accuracies that can be achieved in clear atmospheres. An error budget, derived from single channel, single footprint matchups, indicates AIRS can be validated to better than 1% in absolute radiance (equivalent to 0.5 K in brightness temperature, at 300 K and 938 cm^{-1}) during early mission operations. The eventual goal is to validate instrument radiances close to the demonstrated pre-launch calibration accuracy of about 0.4% (equivalent to 0.2 K in brightness temperature, at 300 K and 938 cm^{-1}).

Kumar, A., P. J. Minnett, G. Podestà, and R. H. Evans, 2002, Error characteristics of the atmospheric correction algorithms used in retrieval of sea surface temperatures from infrared satellite measurements; global and regional aspects. *Journal of the Atmospheric Sciences*. Submitted

A database of co-temporal and co-located satellite and in situ observation is used to examine the association between brightness temperature differences measured in the thermal infrared channels (T45) of the Advanced Very High Resolution Radiometer (AVHRR) and water vapor (ω) derived form the Special Sensor Microwave Imager (SSM/I). This channel difference is used to estimate the atmospheric correction (due mostly to water vapor absorption) in sea surface temperature (SST) *algorithms. The association between T45 and ω is found to be greatest for tropical latitudes; for mid and high latitudes the association is best during summer. However, the association tends to decrease towards mid and higher latitudes during other periods. SST residual errors (satellite – buoy) show a negative mean in the tropics suggesting undercorrection for water vapor in the tropics. The underestimation is explicitly shown for SST in the high water vapor regimes of the Arabian Sea. In mid and high latitudes, the variability of atmospheric water vapor and air-sea temperature difference contribute to the weaker association between T45 and ω, and results in positive mean SST residual errors. A differential form of SST algorithm that incorporates the use of a "first-guess estimate" that correlates with SST is observed to give least residual errors*

Minnett, P.J., 2003, Radiometric measurements of the sea-surface skin temperature for the validation of measurements from satellites – the competing roles of the diurnal thermocline and the cool skin. *International Journal of Remote Sensing*. Submitted.

It has long been recognized that satellite-borne infrared radiometers measure radiance that is more closely related to the temperature of the skin of the ocean than the sub-surface bulk temperature, but, historically, atmospheric correction algorithm derivation and validation exercises have been conducted using bulk temperatures measured at a depth of a metre or more. A recent validation of sea-surface temperature (SST) fields derived from the Advanced Very High Resolution Radiometer (AVHRR) with skin temperature measurements of the Marine-Atmospheric Emitted Radiance Interferometer (M-AERI) revealed a very low mean bias error, much smaller that was expected given the thermal skin effect which acts to cool the surface with respect to subsurface values by several tenths of a degree. This result does not imply the skin effect is not important – its effect is now well documented in many data sets – but that its effect is being partially compensated by diurnal heating effects. The evidence for this is presented and the consequences in terms of validating satellite-derived SSTs and of merging data from sensors with different satellite overpass times are discussed.

Ward, B., R. Wanninkhof, P.J. Minnett and M.J. Head.. SkinDeEP: A Profiling Instrument for Upper Decameter Sea Surface Measurements. *Journal of Atmospheric and Oceanic Technology*. Submitted.

The Skin Depth Experimental Profiler (SkinDeEP) is an autonomous, self–contained, hydrodynamic instrument capable of making repeated, high–resolution profiles of temperature and conductivity within the ocean's upper decameter. Autonomous profiling operation is accomplished through SkinDeEP's ability to change its density: positive buoyancy is achieved by pumping air from inside the body of the profiler into an external, neoprene, inflatable sleeve; the instrument sinks when the sleeve is deflated by returning the air to the interior. The sensors are mounted some distance from the top endcap and data are recorded only during the ascending phase of the profile so as to minimize disruption of a naturally occurring scalar structure within the instrument's footprint. Both temperature and conductivity are measured with resolutions in the submillimeter and millimeter range, respectively. Accurate slower sensors are installed for calibration purposes. These data are used to study exchange processes at the air–sea interface, and the structure of the ocean just below.

F.2 Academic Thesis

Hanafin, J.A. On sea surface properties and characteristics in the infrared. Ph.D. Thesis, University of Miami.

F.3 Conference Proceedings and Data Reports:

Minnett, P.J., R.H. Evans, E.J. Kearns and O.B. Brown. Sea-surface temperature measured by the Moderate Resolution Imaging Spectroradiometer (MODIS). Proceedings of the *IEEE International Geosciences and Remote Sensing Symposium.* Toronto, Canada June 24-28, 2002.

F.4 Presentations:

Berendes,T., D. Berendes, R. Welch, E. Clothiaux, E. Dutton, P. Minnett and T. Uttal. Validation of a Neural Network Based MODIS Global Cloud Mask Using Ground Based Instruments. 82nd Annual Meeting of the American Meteorological Society, Orlando, FL. 13-17 January 2002.

Minnett, P.J., Validation of AATSR sea-surface temperatures. *AATSR Commissioning Phase Readiness Review*. Space Research Centre, University of Leicester, UK. 28 January 2002

Minnett, P.J., Use of satellite data to investigate the ocean skin temperature. Department of Physics and Astronomy, University of Leicester, UK. 29 January 2002

Minnett, P. J. Radiometric measurements of air-sea temperature difference. AGU Ocean Sciences Meeting, Honolulu, Hawaii, 11-15 February 2002.

Hanafin, J. A. and P. J. Minnett. Measurements of sea surface emissivity and air-sea heat flux during Gasex 2001. AGU Ocean Sciences Meeting, Honolulu, Hawaii, 11-15 February 2002.

Minnett, P.J. Recent results for the Marine-AERI. Department of Atmospheric and Oceanic Sciences, University of Wisconsin – Madison. April 1, 2002.

Minnett, P.J. Air-Sea Temperature Difference Measured by Ship-Board Infrared Interferometry. Seventh International Conference on Remote Sensing for Marine and Coastal Environments, Miami, Florida, USA, 20 May, 2002.

Hanafin, J. A. and P.J. Minnett. Field measurements of spectral sea surface emissivity. Seventh International Conference on Remote Sensing for Marine and Coastal Environments, Miami, Florida, USA, 20 May, 2002.

Kearns E.J., R.H. Evans, K. Kilpatrick, P.J. Minnett and D.K. Clark. The calibration of MODIS ocean color and sea surface temperature products. Seventh International Conference on Remote Sensing for Marine and Coastal Environments, Miami, Florida, USA, 20 May, 2002.

Minnett, P.J. Spectroradiometric measurements of the sea-surface temperature and air-sea temperature difference. Coastal Studies Seminar, Division of Applied Marine Physics, RSMAS, University of Miami. 23 May, 2002.

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